THIS REPORT HAS BEEN DELIMITED
AND CLEARED FOR PUBLIC RELEASE
UNDER DOD DIRECTIVE 5200.20 AND
NO RESTRICTIONS ARE IMPOSED UPON
ITS USE AND DISCLOSURE.

DISTRIBUTION STATEMENT A

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED.

Armed Services Technical Information Agency

Because of our limited supply, you are requested to return this copy WHEN IT HAS SERVED YOUR PURPOSE so that it may be made available to other requesters. Your cooperation will be appreciated.

AD 37333

NOTICE: WHEN GOVERNMENT OR OTHER DRAWINGS, SPECIFICATIONS OR OTHER DATA ARE USED FOR ANY PURPOSE OTHER THAN IN CONNECTION WITH A DEFINITELY RELATED GOVERNMENT PROCUREMENT OPERATION, THE U. S. GOVERNMENT THEREBY INCURS NO RESPONSIBILITY, NOR ANY OBLIGATION WHATSOEVER; AND THE FACT THAT THE GOVERNMENT MAY HAVE FORMULATED, FURNISHED, OR IN ANY WAY SUPPLIED THE SAID DRAWINGS, SPECIFICATIONS, OR OTHER DATA IS NOT TO BE REGARDED BY IMPLICATION OR OTHERWISE AS IN ANY MANNER LICENSING THE HOLDER OR ANY OTHER PERSON OR CORPORATION, OR CONVEYING ANY RIGHTS OR PERMISSION TO MANUFACTURE, USE OR SELL ANY PATENTED INVENTION THAT MAY IN ANY WAY BE RELATED THERETO.

Reproduced by
DOCUMENT SERVICE CENTER
KNOTT BUILDING, DAYTON, 2, OHIO

UNCLASSIFIED

AD No. 37333
ASTIA FILE COPY

SERIES 3
ISSUE 360

INSTITUTE OF ENGINEERING RESEARCH
BERKELEY, CALIFORNIA

WAVE RESEARCH LABORATORY

STATISTICAL ANALYSIS OF OCEAN WAVES

BY

R. R. PUTZ

JANUARY 1954

UNIVERSITY OF CALIFORNIA

University of California
College of Engineering
Submitted under Contract NR-083-008
with the Office of Naval Research

Institute of Engineering Research
Waves Research Laboratory

Series 3 Issue 360

STATISTICAL ANALYSIS OF OCEAN WAVES

by

R. R. Putz

Berkeley Calif.
Janaury 1954.

University of California
Institute of Engineering Research
Series 3 Issue 360

STATISTICAL ANALYSIS OF OCEAN WAVES *

R.R. Putz

1. In the study of the ocean and its interaction with its environment, there is a need for effective quantitative description of wave activity in the ocean. If the surface is not too irregular, the time history of fluctuations of the water level above some fixed point on the bottom is a useful quantity. Similar data have been obtained for several years by means of submerged pressure-sensitive instruments. The recorded time-history curve of the subsurface pressure for a moderate length of time, twenty minutes, for example, is what we shall refer to as a wave record.

The questions we have been concerned with are: What information is contained in a wave record, and how may a summary of this information be conveniently extracted? We shall describe a mathematical model found useful for interpreting wave records in terms of probability distributions and energy distributions. We shall first introduce auxiliary curves closely related to the original wave-record curve and then show how simple measurements on these curves can be made to yield a description of the energy distribution. We shall then describe some statistical regularities which have been observed in wave records, and describe others which have been deduced as properties of the special theoretical model.

The subject matter of this talk, as far as observational data is concerned, is limited to the time history of pressure fluctuations at a single point, submerged well below the ocean surface, but in relatively shallow water. Some of the methods and results described are equally applicable to other kinds of data.

2. In the lower half of Figure 1 we see a segment of a typical wave record, showing the pressure fluctuation 34 feet below the surface at Pt. Sur, California. The total time interval shown represents about four and one-half minutes, within which from twenty to twenty-five waves pass the recording point. It will be seen that the distance the recording pen has travelled from the center position, as well as the effective vertical velocity and acceleration of the pen, varies irregularly from instant to instant.

Let us suppose that in addition to the original wave-record curve C_0, we construct a new curve C_1 representing the fluctuating steepness, or slope, of the curve C_0 at each point. This curve, which represents the velocity of the recording pen, may be traced for us by a machine if we wish. Applying such a machine to the curve C_1, we shall obtain a curve C_2, representing the velocity of the pen which traces C_1, or the acceleration of the pen which traces C_0. Evidently this process of obtaining a new curve can be imagined to be repeated indefinitely. We call the resulting curves the derived wave-record curves.

* Presented at the 1953 Pacific Section meeting of the American Society of Limnology and Oceanography, Santa Barbara, California 17 June 1953.

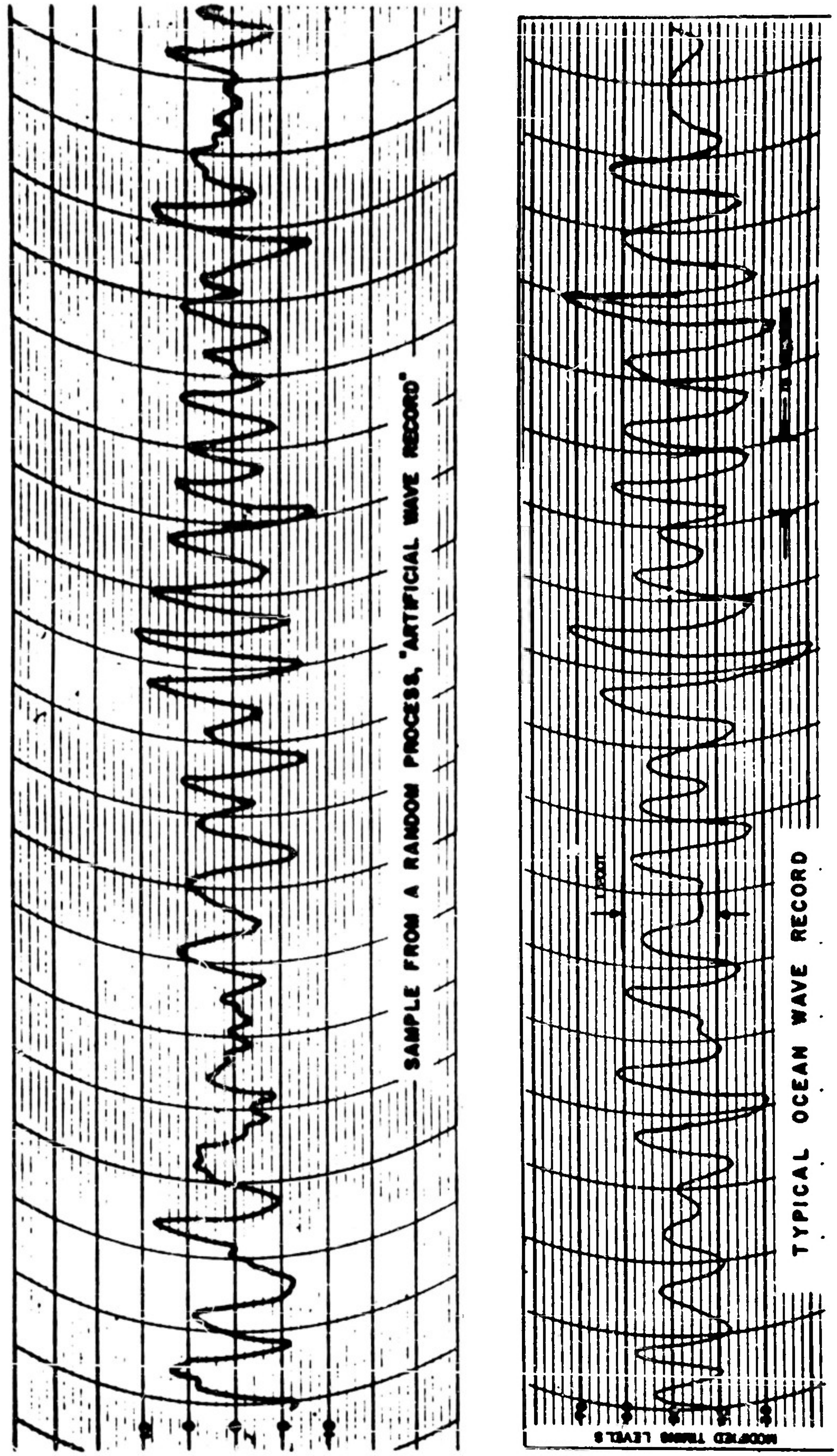

SAMPLE FROM A RANDOM PROCESS, "ARTIFICIAL WAVE RECORD"
TYPICAL OCEAN WAVE RECORD

FIGURE 1

WAVE HEIGHTS AND DERIVED WAVE RECORD CURVES

	C_0, C_1, C_2	Derived wave record curves
	σ_k	Slope of distribution plot of C_k, $k = 0, 1, 2$
(1)	$\omega_k = \sigma_{k+1}/\sigma_k$	$2\pi \cdot$ (Number of zero-crossings of C_k per unit time), $k = 0, 1$
	P_0	Fraction of time C_0 and C_2 lie on opposite sides of meon levels
(2)	$\rho_0 = \cos(\pi P_0) = \omega_0/\omega_1$	Coefficient of correlotion between C_0 and C_2
(3)	$\mu_M = \sqrt{\pi/2} \cdot \rho_0 \sigma_0$	Average peok height ($1/2$ average wave height)

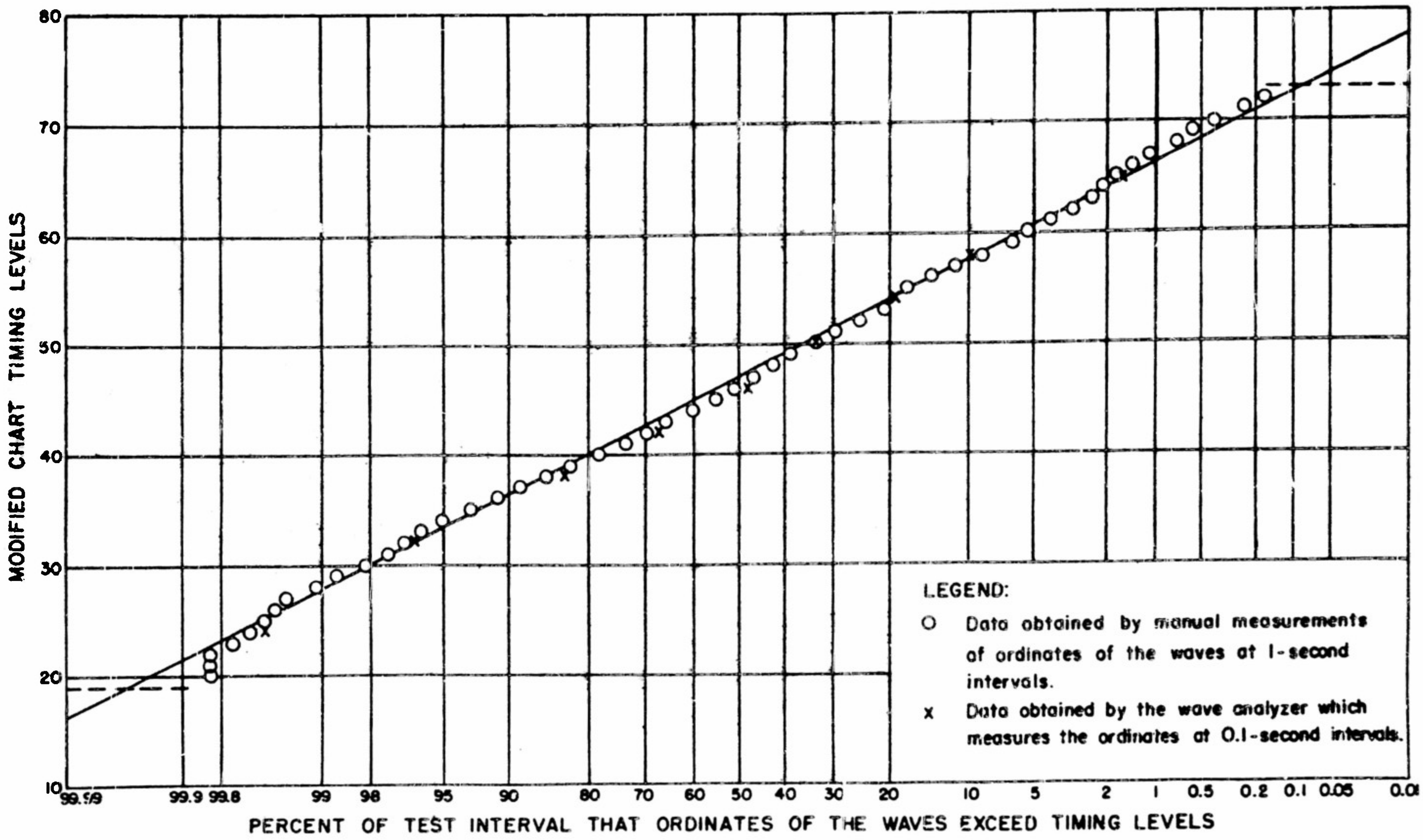
Let us now consider any varying curve and imagine a horizontal straight line drawn across it at an arbitrary height. Suppose the fraction of the time the curve spends below this line is measured. As the line moves upward, this fraction will vary, taking on an increasing series of values which can be plotted on a graph. A typical twenty-minute wave record C_o yields the graph shown in Figure 2, known as its distribution curve. The vertical scale represents the arbitrary vertical level of the line, the horizontal scale the percent of the time the wave-record curve spends below that level. The situation of the plotted points in an approximate straight line is characteristic, and is due to the choice of the horizontal scale, which is the familiar Gaussian-distribution scale, or normal-probability scale.

The significant thing about the ocean-wave records studied is the apparent ability of the Gaussian distribution scale to rectify, very nearly, the plots of the distribution curves, not only for C_o, which has been checked experimentally, but also, according to the theory, for C_1 and C_2. In each case there will be some chart level, called the mean level, below which the curve spends just fifty percent of its time. The mean level for the curves C_1 and C_2 turns out to be zero, while for C_o it can be arbitrarily set equal to zero by making all vertical measurements of the curve height from the mean level on the original wave record.

Since the mean levels are all zero, the only feature distinguishing these straight-line distribution curves is their slope. We take as the measure of this slope the difference between the height of the line at the 84 percent level and its height at the mean level. This difference is the so-called standard deviation or dispersion of the distribution. For the wave-record curves C_o, C_1, C_2, we shall obtain in this way slopes denoted by $\sigma_o, \sigma_1, \sigma_2$, respectively.

3. We find an interpretation of these three quantities if we next consider the number of times, denoted by N_o and N_1, that C_o and C_1, respectively, pass through their mean levels (i.e. through the zero level). If the total length of the wave-record is T seconds, then the average number of zero-level crossings per second will be N_o/T and N_1/T, respectively; multiplying by π, we define the quantities $\omega_o = \pi N_o/T$ and $\omega_1 = \pi N_1/T$. Theory predicts that $\omega_o = \sigma_1/\sigma_o$ and $\omega_1 = \sigma_2/\sigma_1$, relating the slopes of the distribution plots to the mean zero-level crossing frequencies.

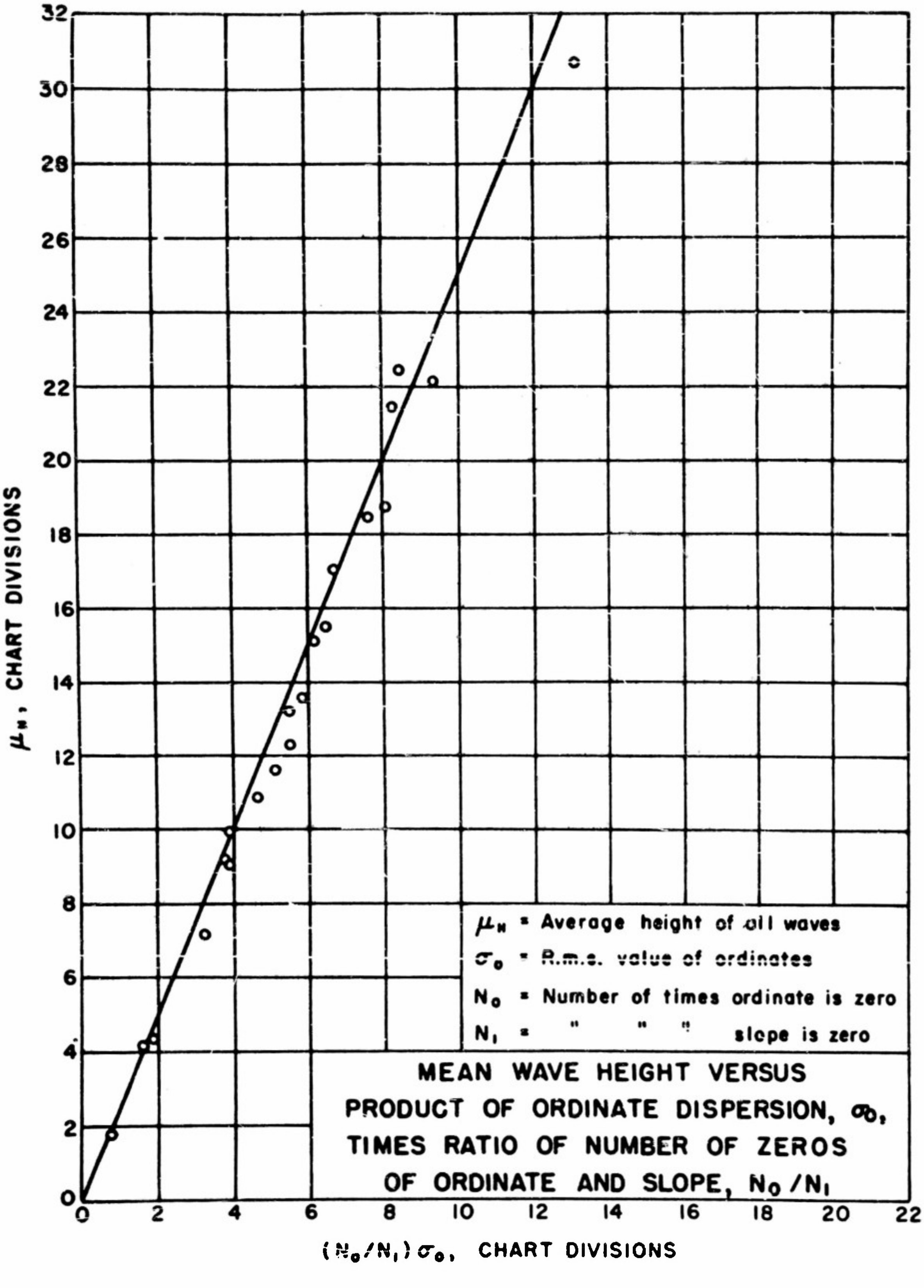
Let us look further at the curves C_o and C_2, measuring the fraction of the time that the two simultaneously lie on opposite sides of their mean levels -- one curve above its mean level while the other is below its mean level, or vice versa. Call this fraction P_o. If we refer to a trigonometric table of cosines, the value of the quantity ρ_o defined as $\cos(\pi P_o)$ is, according to the theory, a measure of the degree to which a point on one of the curves C_o or C_2 determines the location of the corresponding point at the same instant on the other. The quantity ρ_o is called the coefficient of correlation between C_o and C_2. Theory predicts that $\rho_o = -(\omega_o/\omega_1) = -(N_o/N_1)$, showing the negative nature of this correlation. This relation has been found to check experimentally within a few percent, for twenty-minute wave records.



CUMULATIVE DISTRIBUTION FUNCTION OF THE ORDINATES OF THE WAVES

HYD-502

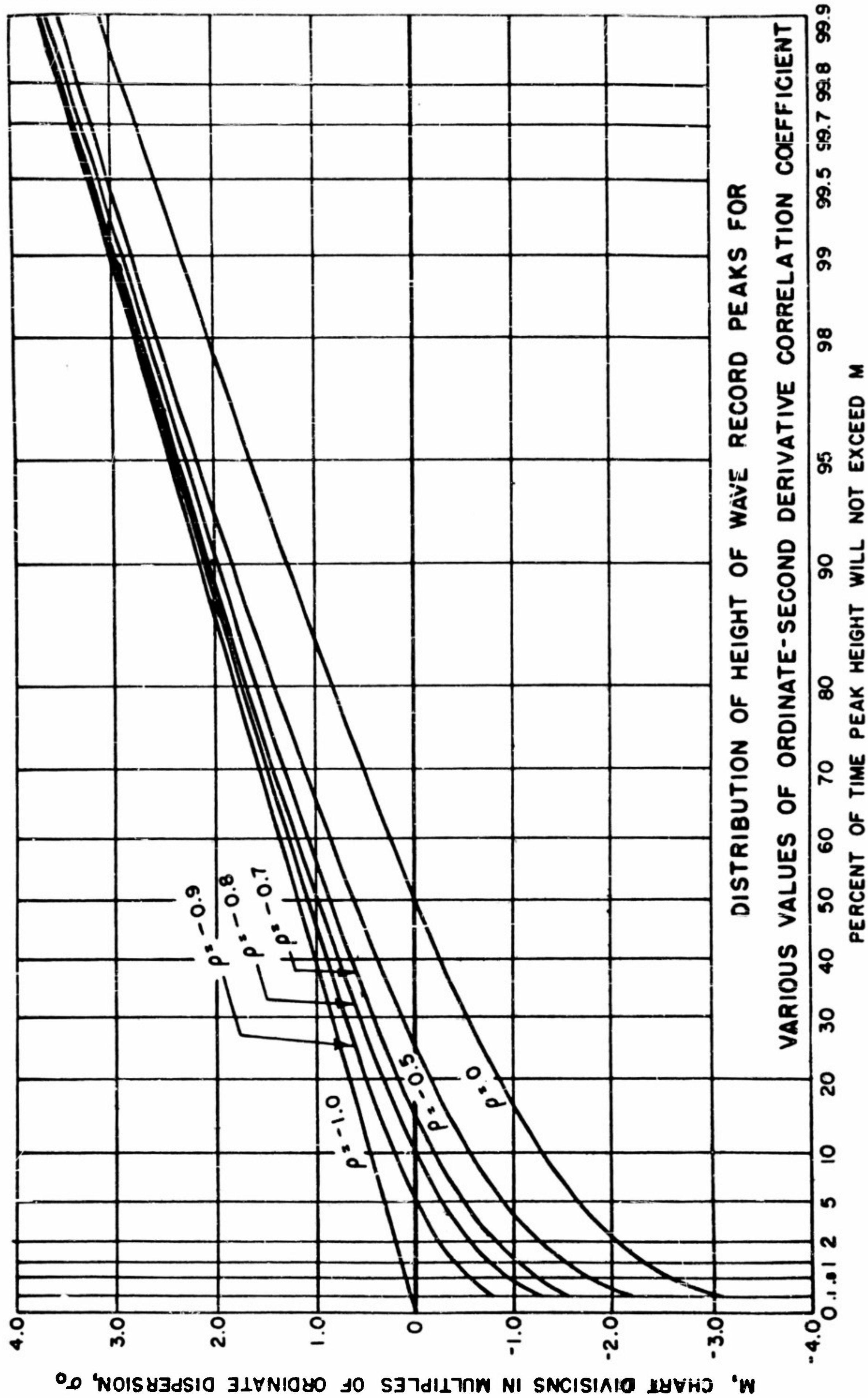
FIGURE 2



MEAN WAVE HEIGHT VERSUS PRODUCT OF ORDINATE DISPERSION, σ_0, TIMES RATIO OF NUMBER OF ZEROS OF ORDINATE AND SLOPE, N_0/N_1

HYD-6577

FIGURE 3



HYD-6578

FIGURE 4

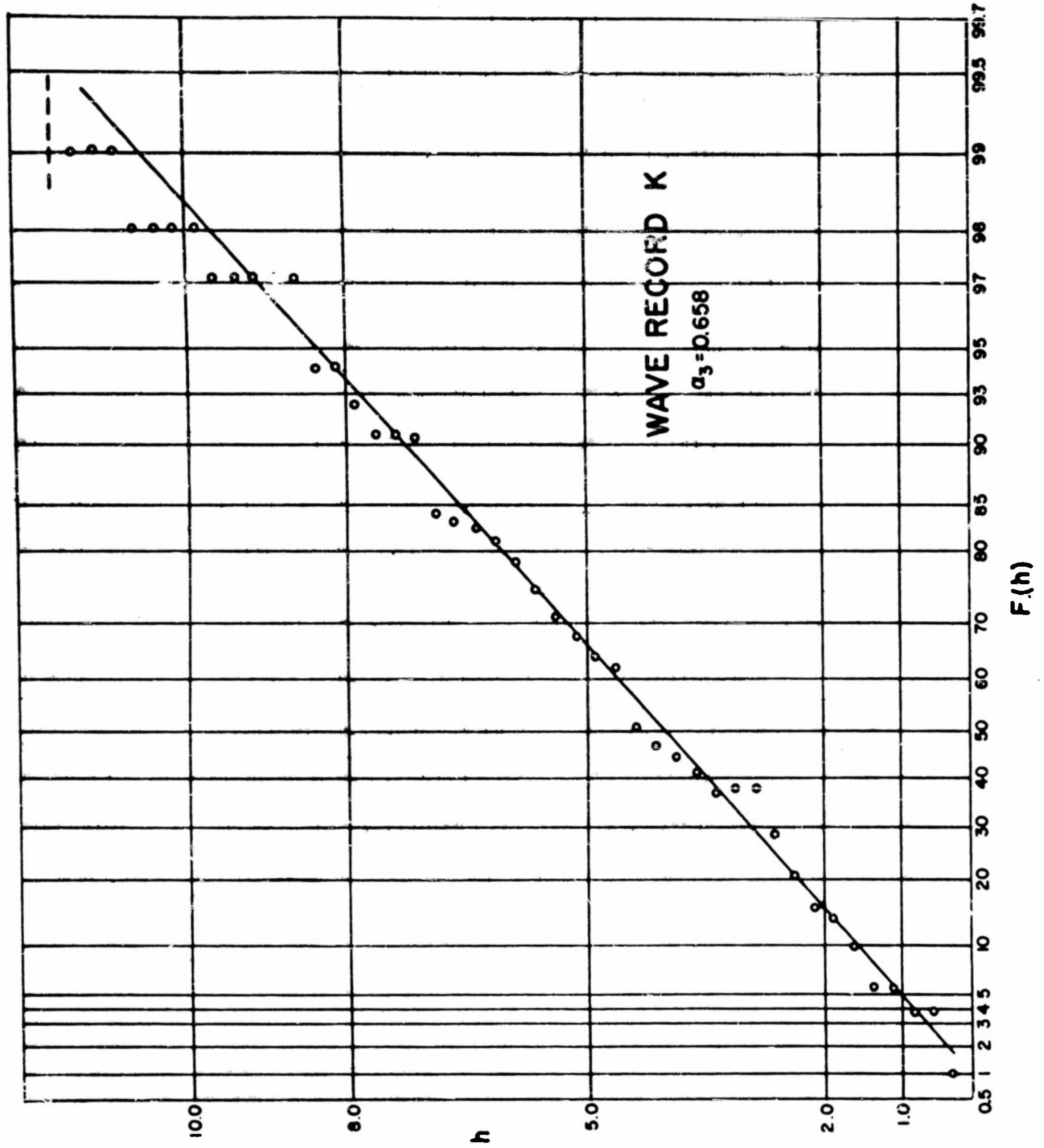

WAVE RECORD K
a3=0.658
F(h)
h
10.0
8.0
5.0
2.0
1.0
0.5
1
2
3
4
5
10
20
30
40
50
60
70
80
85
90
93
95
97
98
99
99.5
99.7

FIGURE 5

4. A further interpretation of the distribution slope σ_0 for the curve C_0 is possible if we examine the heights of the peaks on this curve. If these heights, measured from the mean level, are averaged, the resulting quantity μ_M is just one-half the average trough-to-crest wave height μ_H. We have $\mu_M = (\pi/2)^{\frac{1}{2}} (-\rho_0) \sigma_0$, a theoretical relation which checks experimentally to within a few percent. This is shown in Figure 3, where μ_H, i.e. $2\mu_M$, is plotted against $(N_0/N_1) \sigma_0$ for each of a number of twenty-minute wave records. The straight line representing the theoretical relation has slope $(2\pi)^{\frac{1}{2}}$.

The dependence of the mean peak height μ_M solely on σ_0 and ρ_0 follows from the fact that these two quantities determine the entire distribution of peak heights. Figure 4 shows the theoretical distribution of peak heights for various values of ρ_0, when σ_0 is taken as the vertical scale unit on the record chart. The horizontal scale gives the percent of the wave peaks which occur below any chart level M. This scale has been chosen to correspond to the so-called Rayleigh distribution, which the peak heights follow more and more closely as ρ_0 approaches the value minus one. It may be noted that the probability of a peak occurring below the mean (zero) level is just $\frac{1}{2}(1 + \rho_0)$, which is close to zero for numerical values of ρ_0 near unity.

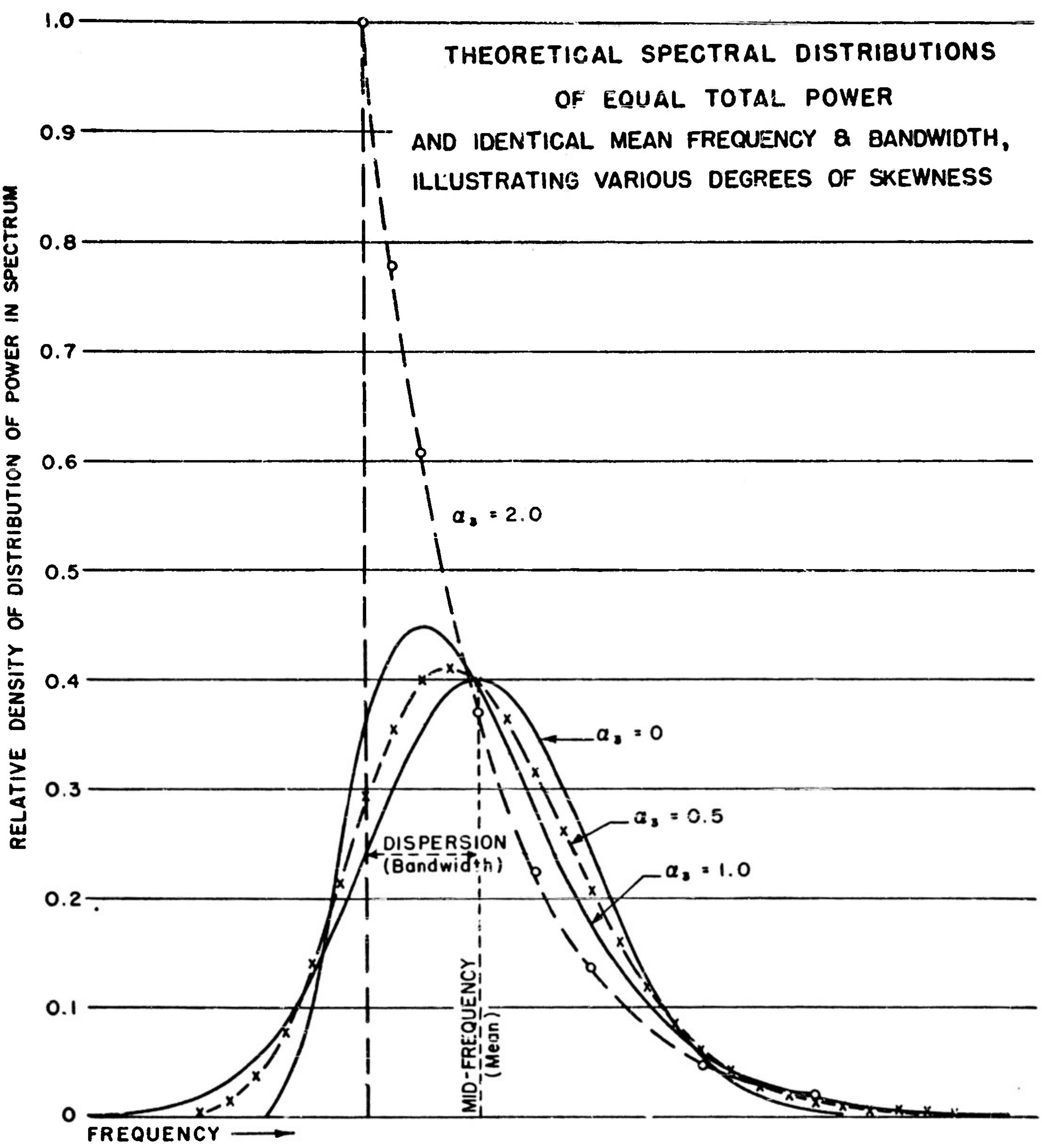
Figure 5 shows a typical observed distribution of wave heights, measured from trough to crest and plotted against a horizontal Rayleigh scale on which may be read the percent of wave heights below any height h. The good fit of the straight line represents further agreement, in a twenty-minute wave record, with the theory.

The Rayleigh distribution enters into the analysis of wave records in another way. It can be shown that this distribution is the one followed by the ordinates on an auxiliary curve, associated with the original wave-record curve, and known as its envelope. The envelope concept is closely related to one aspect of the already-mentioned theoretical model.

5. The mathematical probability model approximating the wave records has two aspects. The first is concerned with certain curve-height, or ordinate distributions similar to those already considered. The second is concerned with a theoretical distribution of wave energies over a continuous set of elementary waves of all possible frequencies.

The combination of these two kinds of distributions characterizes what has been called a random process or a semi-determinate function. The capacity of such a theoretical model to describe ocean-wave records is illustrated by comparing a sample taken from such a process and a typical wave record. In Figure 1 is shown the two curves together; the upper one was generated by first specifying three fixed numbers, characterizing the spectrum, and then consulting a table of random numbers published by the Cambridge University Press.

Each of the distributions appearing in the general mathematical model may be specified by a curve. The curve representing the energies of elementary waves is called the spectral-energy distribution curve. This distribution of energy is of fundamental importance for the study of the generation, propagation and mechanical effects of waves. Its direct computation presents certain practical difficulties and would appear to be too time-consuming for routine wave-data analysis. Our problem is the partial characterization of the spectral-distribution curve by means of a very few selected quantities.



HYD-6579

FIGURE 6

In Figure 6 are shown certain members of a mathematical family of spectral distribution curves which are completely characterized by four numbers each. Three of these numbers are the same for each of the spectral distribution curves shown. These common parameters are: (1) the total area enclosed by the curve, which turns out to be σ_0^2, (2) the mean spectral frequency, μ_ω, averaged over the spectral energy distribution, and (3) the standard deviation or bandwidth σ_ω of the spectral energy distribution. The fourth number, denoted by α_3, is, for the family in Figure 6, a measure of the degree of asymmetry or skewness of the spectral-distribution curve. It is seen that there is a marked degree of asymmetry when $\alpha_3 = + 2.0$.

It is clear that the higher the spectral energy distribution curve, the greater the enclosed area, so that σ_0^2 represents the total energy for the wave record. Likewise, the spectral bandwidth is a measure of how widely the energy is dispersed over all possible frequencies. A quantity of some interest is the relative bandwidth δ_ω, defined as the ratio $\sigma_\omega / \mu_\omega$, measuring the degree of spread of the energy relative to the midband location at which it is centered.

6. It is possible that for certain purposes a spectral distribution may be adequately described by means of a few quantities, provided something is known about the general shape of the spectral curve. With present knowledge of typical spectrum shapes, the quantities just described would appear to be useful for a general characterization of the energy distribution. In fact, for simple spectra the three numbers σ_0^2, μ_ω, and σ_ω, may prove to be adequate for many purposes if supplemented by one or two other parameters (such as α_3) to indicate spectral shape.

We can now describe how this kind of information about the spectral distribution may be obtained from the wave record. This description will require the concept of the envelope curve mentioned earlier. We shall show later how in special cases approximate information about the spectral distribution may be obtained by considering only the previously-defined derived wave-record curves.

For a regular wave system whose spectral energy is concentrated at a single frequency, one's intuition rightly suggests as the envelope curve, the horizontal straight line passing through all the peaks on the wave-record, which has in this case a simple sinusoidal form. For more general wave systems, the envelope curve may be determined mathematically, but its exact location on the chart is not as easy to visualize. It may be said, however, that if the wave-record curve is not too irregular, the envelope curve comes close to each peak.

Suppose for a given wave-record curve the envelope is drawn and a new curve then constructed at each point in the following way: Form the squares of the heights of the curve and of its envelope at each point, subtract the former from the latter, and extract the square root of the difference. The result is the numerical value of the height of a point on a new curve said to be conjugate to the original curve. The entire operation leading to the drawing of the conjugate curve may, in certain cases, be carried out by machines with sufficient accuracy.

7. If C_0^* and C_1^* are the curves conjugate to C_0 and C_1 respectively, these four curves may be paired together in six different ways. If for each pair we measure the fraction of the time the two curves lie on opposite sides of their mean levels, we find that except for the pairs (C_0, C_1^*) and (C_1, C_0^*), this fraction is always one-half, independent of the spectrum of the original curve C_0. For the remaining two pairs, this fraction depends on the spectrum of C_0, containing in both cases essentially the same spectral information, which, it turns out, is just what is needed for computing the mean spectral frequency μ_ω for the wave-record curve C_0.

Let P_0^* be the fraction of the time the curves C_0 and C_1^* lie on opposite sides of their mean levels. Then ρ_0^*, the value given in a table of cosines for the angle (πP_0^*), will be the coefficient of correlation between C_0 and C_1^*. This quantity, together with the mean zero-level crossing frequency ω_0, determines the mean spectral frequency. In fact, we have $\mu_\omega = \rho_0^* \omega_0$. Further, it may be shown that $\mu_\omega = -\rho_0 \rho_0^* \omega_1$, where ω_1, as before, is the mean wave-crest frequency, measured by counting all peaks no matter how high. The correction factor $(-\rho_0 \rho_0^*)$ necessary to convert from mean peak-to-peak frequency, ω_1, to mean spectral-distribution frequency, μ_ω, may be as small as 0.7 for a typical pressure record. The quantity $(-\rho_0 \rho_0^*)$ is in all practical cases less than unity and smaller that the similar quantity ρ_0^*, which is the correction factor required when ω_0 is used.

It will be seen that if μ_ω is regarded as a suitable measure of mean wave frequency, then ω_0 and ω_1 probably would not be, since each of these two quantities includes information about the spectral bandwidth as well as about the center position of the spectral band. The extent to which frequency bandwidth (σ_ω) thus enters into the mean zero-crossing frequency (ω_0), which might otherwise appear to be a simple measure of midband frequency, depends upon the relative bandwidth $(\delta\omega)$ of the spectral distribution.

8. If we consult the trigonometric tables once more, finding the numerical value of the tangent of the angle (πP_0^*), we obtain the relative bandwidth itself. The smaller this tangent, the more nearly the wave-record curve will resemble a single-frequency wave system. The smaller this quantity, the more closely correlated will be all the derived and conjugated curves obtained from C_0 -- with the exception of those which simultaneously lie on opposite sides of their means exactly one half of the time, regardless of C_0's spectral distribution. Figure 7 shows how, for a rather wide class of spectral distributions including those shown in Figure 6, the values of ρ_0 and $\delta\omega$ determine one another with increasing precision as the relative bandwidth decreases. The region between the two curves shown represents the possible variation of these quantities, the upper curve corresponding to $\alpha_3 = 0.0$, the lower to $\alpha_3 = +2.0$. As the relative bandwidth decreases, the distribution of peak heights becomes more nearly like that of the envelope. The envelope curve itself then approaches the wave-record curve at each peak of the latter.

The case of small relative bandwidth is significant since most moderately deep pressure records seem to fall into this category with sufficient precision to allow certain narrow-band approximations to be made, in most cases with an error of a few percent. We then have the following approximate formulas requiring no knowledge of the conjugate wave-record curve. In terms

WAVE SPECTRUM AND CONJUGATED WAVE RECORD CURVES

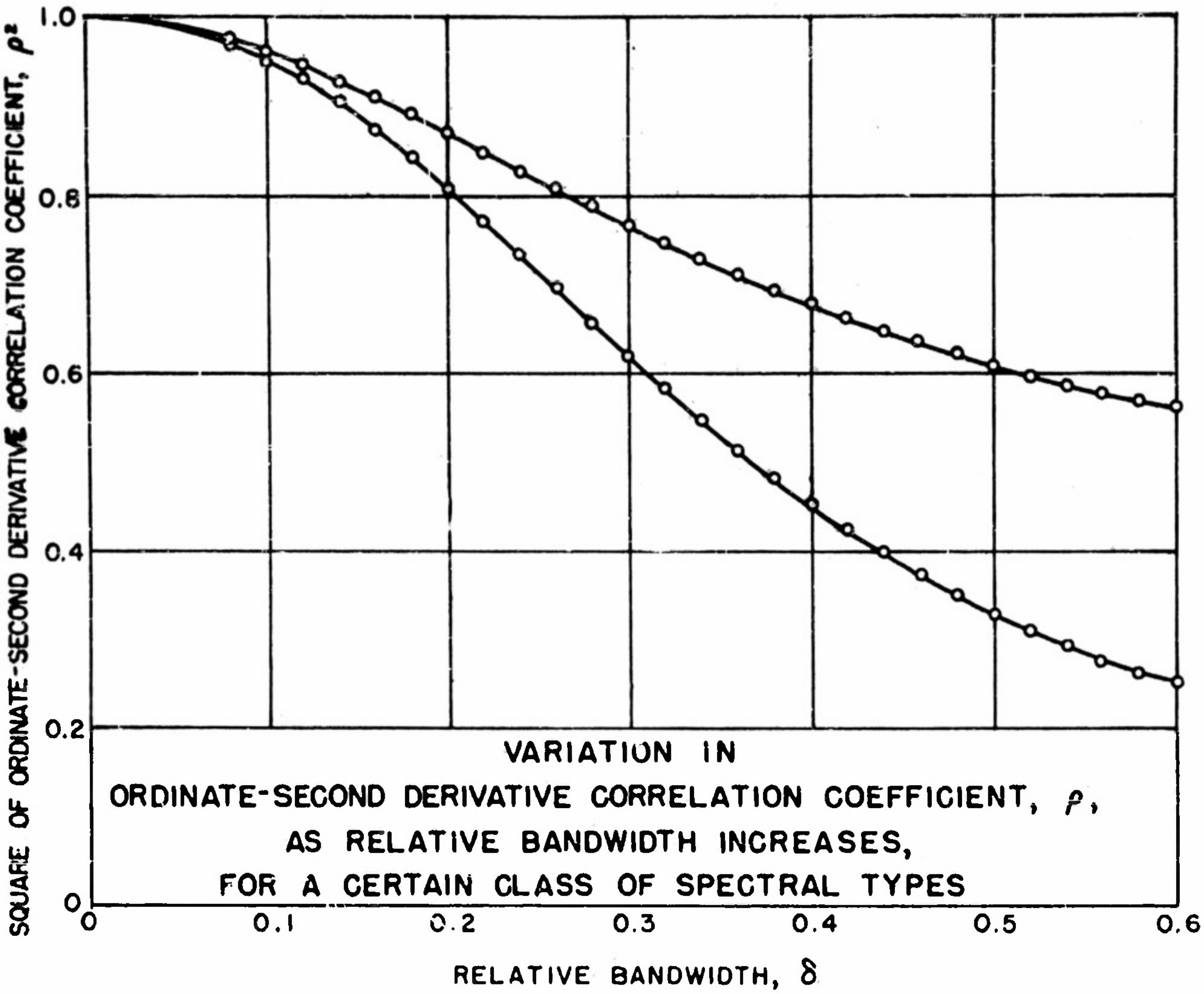
	C_0^*, C_1^*	Conjugated wave record curves
	P_0^*	Fraction of time C_0 and C_1^* lie on opposite sides of mean levels
(4)	$\rho_0^* = \cos(\pi P_0^*)$	Coefficient of correlation between C_0 and C_1^*
(5)	$\mu_\omega = \rho_0^* \omega_0 = \rho_0 \rho_0^* \omega_1$	Mean frequency in spectral distribution
(6)	$\sigma_\omega = (\omega_0^2 - \mu_\omega^2)^{1/2}$	Dispersion of frequency in spectral distribution

NARROW-BAND APPROXIMATIONS

(7) $\delta_\omega = \sigma_\omega / \mu_\omega = \tan(\pi P_0^*)$ Relative bandwidth of spectral distribution

(8) For small δ_ω

$$\begin{cases} \text{Relative bandwidth} & \tfrac{1}{2}\tan(\pi P_0) \\ \text{Mean frequency} & [1 - \tfrac{1}{8}\tan^2(\pi P_0)]\,\omega_0 \\ \text{Mean wave height} & [1 - \tfrac{1}{2}\tan^2(\pi P_0)]\,\sqrt{2\pi}\;\sigma_0 \end{cases}$$



HYD-6580

FIGURE 7

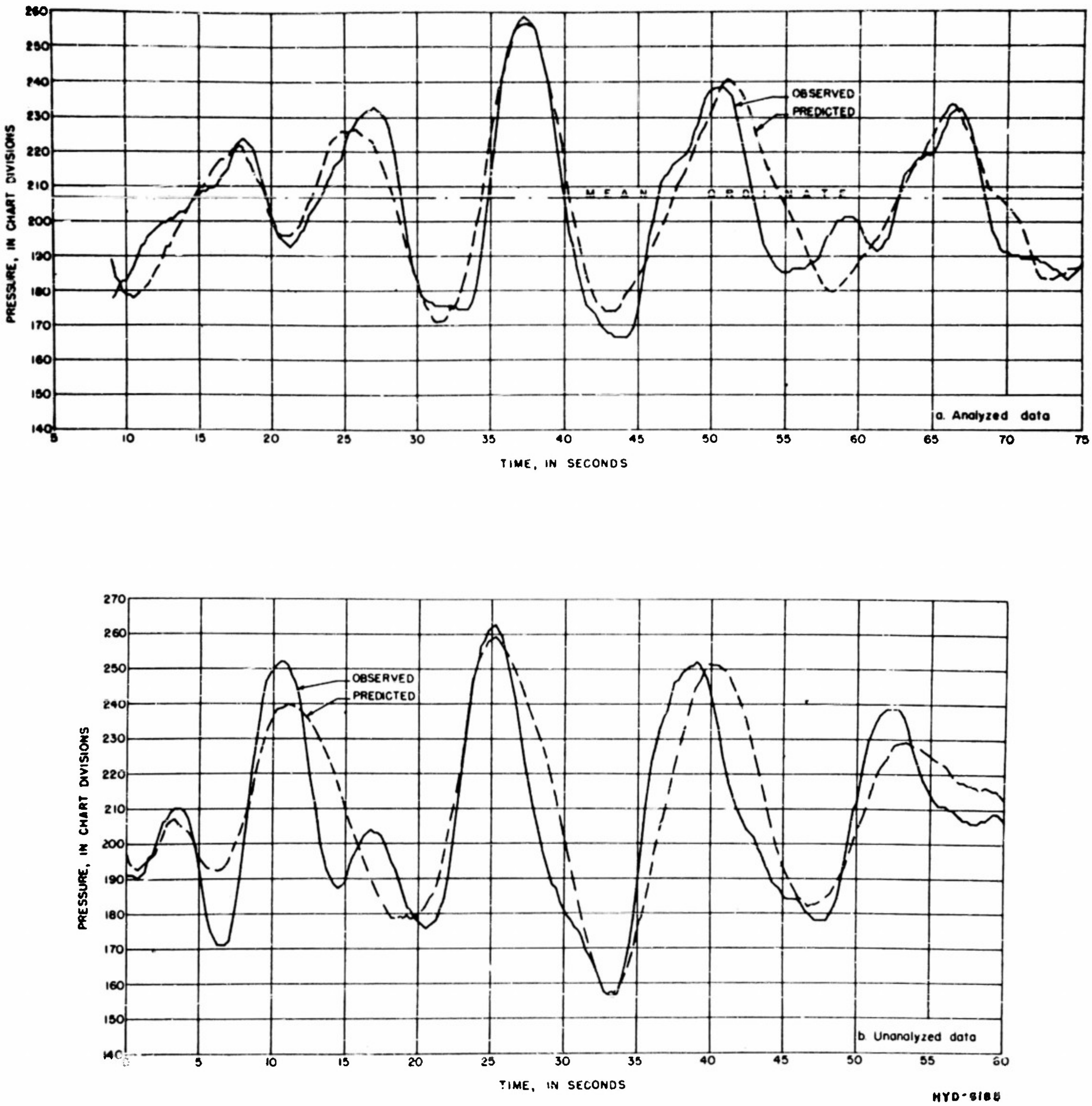
of the three quantities σ_0, ω_0, ρ_0, we have when δ_ω is small,

$$\left.\begin{array}{ll} \text{relative bandwidth} & \sim \frac{1}{2}\tan(\pi P_0) \\ \text{mean frequency} & \sim \left[1 - \frac{1}{8}\tan^2(\pi P_0)\right]\omega_0 \\ \text{mean wave height} & \sim \left[1 - \frac{1}{2}\tan^2(\pi P_0)\right] (2\pi)^{\frac{1}{2}}\sigma_0 \end{array}\right\} \quad (3)$$

9. The random process interpretation of wave records deals directly with the properties of the unobserved part of a wave system, for it makes the basic assumption that the wave record is only a sample from a continuing process. This approach has been used to predict, by a least-squares method, the behavior of waves at one time and place from the behavior of waves observed at a time and place nearby. In the lower half of Figure 8 are shown the wave record observed, and that predicted, for the same point, using the wave record observed at a point approximately 200 feet seaward. This prediction was made after an initial analysis, not of these two wave records, but rather of two wave records made at these points thirty minutes earlier. The prediction method requires the determination of but four numbers from each of the spectral distributions involved. The upper half of Figure 8 shows the results when the four numbers are determined from these wave records themselves, rather than from earlier wave records at the same points.

10. A word of qualification should be added to the theoretical results that have been indicated. All of the quantities whose relations to each other have been described are assumed to have been calculated from wave records of sufficient length to minimize random sampling errors. There is some evidence that, for describing ocean waves, a twenty-minute record may be adequate, although for some purposes, longer records may be necessary. Shorter wave records, of course, reduce the likelihood of significant changes in the wave spectrum during the time covered by the record, due for example, to meteorological conditions.

It may be suggested that the quantities described, when continuously obtained from field installations by routine mechanized analysis, will be a useful supplement to the results of an occasional more refined, time-consuming analysis of the wave spectrum. Quantitative information would then be availabel during the life history of a storm describing changes in the wave spectrum as they occur. Numerical results would be available for investigating both the generation of waves and their ultimate effect on the coast and other structures, as well as for the establishment of wave-climate conditions at various locations and seasons of the year.



OCEAN WAVE PREDICTION OVER 204-FOOT DISTANCE, LEAST SQUARE METHOD

FIGURE 8

DISTRIBUTION LIST
Unclassified Technical Reports

Copies	Addressee
13	Director Inst. of Engineering Research University of California Berkeley 4, Calif.
1	Chief of Naval Operations Navy Dept. Attn: Op-533D Washington 25, D.C.
2	Geophysics Branch, Code 416 Office of Naval Research Washington 25, D.C.
6	Director, Naval Research Lab. Attn: Tech. Information Officer Washington 25, D.C.
2	Officer-in-Charge Office of Naval Resea rch, London Br. Navy No. 100 FPO. New York, N.Y.
1	Office of Naval Research Branch Office 346 Broadway New York, 13, N.Y.
1	Office of Naval Research, Branch Office 10th Floor, The John Crerar Library 86 E. Randolph St. Chicago, Ill.
1	Office of Naval Research, Br. Off. 1030 East Green St. Pasadena, 1, Calif.
1	ONR. Branch Office 1000 Geary St. San Francisco, Calif.
1	ONR. Resident Representative University of Calif. T-3
1	Office of Technical Services Dept of Commerce Washington 25, D.C.
5	Armed Services Tech. Information Center Documents Service Center Knott Bldg, Dayton 2, Ohio.

Copies	Addressee
1	Asst. Secty of Defense for Research and Development Attn: Comm. on Geophys. & Geography Pentagon Bldg. Washington 25, D.C.
2	Asst. Naval Attache for Res. American Embassy Navy No. 100 FPO, New York, N.Y.
2.	U.S. Bureau of Ships Navy Dept. Washington 25, D.C. Attn: Code 847
1	Commander Naval Ord. Lab. White Oak Silver Springs, Md.
1	Commanding General, Res. & Devel. Dept of the Air Force Washington 25, D.C.
1	Chief of Naval Research Navy Dept. Code 466 Washington 25, D.C.
8	U.S. Navy Hydrographic Office Washington 25, D.C. Attn: Div. of Oceanography
2	Director U.S. Navy Electronics Lab. San Diego 52, Calif. Attn: Codes 550, 552
1	Chief Bu. Yards and Docks Navy Dept. Washington 25, D.C.
1	Commanding General Research and Development Div. Dept. of the Army Washington 25, D.C.
1	Commanding Officer Air Force Comb. Research & Development Center CRQST-2 230 Albany St. Cambridge 39, Mass.

Copies	Addressee
1	Project AROWA, U.S. Naval Air Sta. Bldg R-48 Norfolk, Virginia
1	Dept of Aerology U.S. Naval Post Graduate School Monterey, California.
1	Commandant (OAO), U.S. Coast Guard 1300 E. St. N.W. Washington 25, D.C.
1	Director, U.S. Coast and Geodetic Survey Dept of Commerce Washington 25, D.C.
1	U.S. Army, Beach Erosion Board 5201 Little Falls Rd. N.W. Washington 16, D.C.
1	Dept of the Army Office of the Chief of Engineers Attn: Library Washington 25, D.C.
1	Mr. A.L. Cochran Chief, Hydrology and Hydr. Branch U.S. Corps of Engrs. Gravelly Point, Washington, D.C.
1	Commanding Officer U.S. Naval CE Res. and Evaluation Lab. Construction Battn. Center Port Hueneme, Calif.
1	Dept. of Engineering University of Calif. Berkeley, Calif.
1	The Oceanographic Inst. Florida State University Tallahassee, Florida
1	Head, Dept. of Oceanography University of Washington Seattle, Washington
1	Bingham Oceanographic Foundation Yale University, New Haven, Connecticut
1	Dept. of Conservation Cornell University Ithaca, N.Y. Attn: Dr. J. Ayers
1	Director, Lamont Geological Observ. Torrey Ckiff Palisades, N.Y.

Copies	Addressee
1	Allen Hancock Foundation University of Southern Calif. Los Angeles 7, Calif.
1	Director Narragansett Marine Lab. Kingston, R.I.
1	Director Chesapeake Bay Inst. Box 426 A RFD #2 Annapolis, Md.
1	Head, Dept. of Oceanography Texas A & M College College Station, Texas
1	Dr. Willard J. Pierson New York University University Heights New York 53, N.Y.
1	Director Hawaii Marine Lab. University of Hawaii Honolulu, T.H.
1	Director Marine Lab., University of Miami Coral Gables, Fla.
1	Head, Dept of Oceanography Brown University Providence, R.I.
1	Dept of Zoology Attn: Dr. H. Haskins Rutgers University New Brunswick, N.J.
2	Library Scripps Inst. of Oceanography La Jolla, Calif.
2	Director Woods Hole Oceanographic Inst. Woods Hole, Mass.
2	Director U.S. Fish and Wildlife Serv. Dept of the Interior Attn: Dr. L.A. Walford Washington 25, D.C.
1	U.S. Fish and Wildlife Serv. P.O. Box 3830 Honolulu, T.H.

Copies	Addressee
1	U.S. Fish and Wildlife Serv. Woods Hole, Mass.
1	U.S. Fish and Wildlife Serv. Fort Crockett, Galveston, Texas
1	U.S. Fish and Wildlife Serv. 450 B. Jordan Hall Stanford University Stanford, Calif.
1	U.S. Waterways Experiment Station Vicksburg, Miss.
1	U.S. Engineers Office San Francisco Dist. 180 New Montgomery St. San Francisco 19, Calif.
1	U.S. Engineers Office Los Angeles Dist. P.O. Box 17277, Foy Station Los Angeles 17, Calif.
1	Office of Honolulu Area Engrs. P.O. Box 2240 Honolulu, T.H.
1	Chairman, Ship to Shore Cont. Bd. U.S. Atlantic Fleet Commander Amphib. Group 2 FPO, N.Y., N.Y.
1	Commander, Amphibicus Forces Pacific Fleet San Francisco, Calif.
1	Commander, Amphibious Training Command U.S. Pacific Fleet San Diego, 32, Calif.
1	Dr. M. St. Denis David Taylor Model Basin U.S. Navy Dept. Washington 25, D.C.
1	Dist. Engineer, Corps of Engrs. Jacksonville Dist. 575 Riverside Ave. Jacksonville, Fla.
1	Missouri River Division Corps of Engrs. U.S. Army P.O. Box 1216 Omaha 1, Nebraska

Copies	Addressee
1	Commandant Marine Corps School Quantico, Va.
1	Sir Claude Inglis, CIE. Division of Hydraulics Research % Office of Naval Research Navy No. 100 FPO. N.Y., N.Y.
1	Commandant Hq. Marine Corps AO-4E Arlington Annex Washington, D.C.
1	Chief, Andrews Air Force Base Washington 25, D.C. Attn: Mr. Stone
3	U.S. Army Transportation Corps. Research and Development Fort Eustis, Va. Attn: Mr. J.R. Cloyd
3	British Joint Services Mission Main Navy Bldg. Washington 25, D.C.
1	California Academy of Sciences Golden Gate Park San Francisco, Calif. Attn: Dr. R.C. Miller.

Armed Services Technical Information Agency

Because of our limited supply, you are requested to return this copy WHEN IT HAS SERVED YOUR PURPOSE so that it may be made available to other requesters. Your cooperation will be appreciated.

AD 37333

NOTICE: WHEN GOVERNMENT OR OTHER DRAWINGS, SPECIFICATIONS OR OTHER DATA ARE USED FOR ANY PURPOSE OTHER THAN IN CONNECTION WITH A DEFINITELY RELATED GOVERNMENT PROCUREMENT OPERATION, THE U. S. GOVERNMENT THEREBY INCURS NO RESPONSIBILITY, NOR ANY OBLIGATION WHATSOEVER; AND THE FACT THAT THE GOVERNMENT MAY HAVE FORMULATED, FURNISHED, OR IN ANY WAY SUPPLIED THE SAID DRAWINGS, SPECIFICATIONS, OR OTHER DATA IS NOT TO BE REGARDED BY IMPLICATION OR OTHERWISE AS IN ANY MANNER LICENSING THE HOLDER OR ANY OTHER PERSON OR CORPORATION, OR CONVEYING ANY RIGHTS OR PERMISSION TO MANUFACTURE, USE OR SELL ANY PATENTED INVENTION THAT MAY IN ANY WAY BE RELATED THERETO.

Reproduced by

DOCUMENT SERVICE CENTER

KNOTT BUILDING, DAYTON, 2, OHIO

UNCLASSIFIED